Studying Feedback in Clusters with Constellation-X

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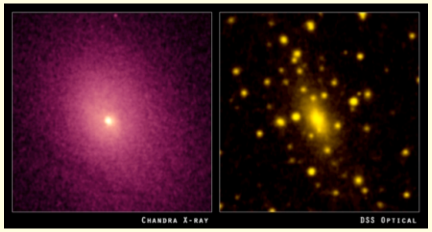

Fig. 1: Image of the 100 million degree gas in the Abell 2029 cluster (left) taken with NASA's Chandra X-ray observatory; galaxies including the central cD are seen in the visual image at right. Each image is several hundred kpc across.

Galaxy clusters are collections of hundreds of galaxies embedded in atmospheres of X-ray emitting plasma and dark matter (Fig. 1). With masses of 10^{13} to 10^{15} solar masses, and diameters of several megaparsecs, galaxy clusters are among the largest structures in the Universe. They reveal how much matter exists in the Universe and how it is apportioned between ordinary matter (the chemical elements), dark matter, and dark energy. The history of heating, cooling, and chemical enrichment by galaxies and supermassive black holes is imprinted on their X-ray atmospheres. Outbursts from active galactic nuclei (AGN) deposit more than 10^{62} erg into the atmospheres (Fig. 3), regulating the cooling of the gas, boosting its entropy level ("preheating"), and governing the growth of giant elliptical galaxies and supermassive black holes. Con-X will further our knowledge of feedback in clusters gained by the Chandra and XMM-Newton observatories as follows:

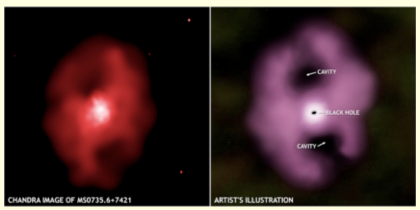

Fig. 2: X-ray image of the hot gas in the redshift 0.22 cluster MS0735+7421 taken with Chandra. Cavities like these, roughly 1 arcmin (200 kpc) across, can be closely studied with Con-X. The AGN that created the cavities and surrounding shock fronts released 6×10^{61} erg. The cD's supermassive black hole powering the cavites grew by 3×10^{8} solar masses over 100 Myr. One trillion solar masses of gas were displaced (McNamara et al. 2005, *Nature, 433, 45)*

- entropy profiles of the hot gas (Fig. 3) in distant clusters will reveal the history of feedback from AGN, galactic winds, and mergers
- observations of cavities, ripples, and shock fronts in clusters like Perseus (Fig. 4) and MS0735.6+7421 (Fig. 2) will measure AGN outburst strengths and the level of gas heating, and they will constrain the composition and ages of radio jets
- the velocity, metal, and temperature distributions in the hot gas will reveal the metal enrichment history and trace circulation patterns driven by AGN outflows and mergers
- spectra (Fig. 5) of the metal lines below 1 keV (e.g., Fe L) will be sensitive enough to determine whether the gas fueling star formation, nebular emission (Fig. 4), and supermassive black holes in cD galaxies cooled and condensed out of the hot atmospheres

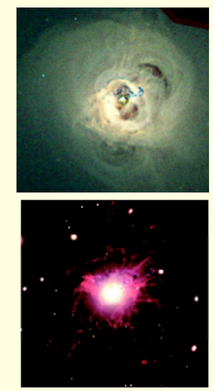

Fig. 4 (top) Deep Chandra image of the Perseus cluster showing cavities and ripples from a series of AGN outbursts. (botttom) Nebular emission from gas being dragged out of NGC 1275 by the rising cavities. The gas is fueling star formation in the cD. (Fabian et al. 05, Conselice et al. 2001, AJ, 122, 2281)

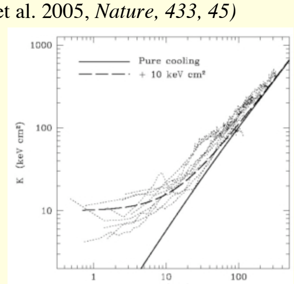

Fig. 3: (left) Entropy profiles ($T/n_e^{2/3}$) of the hc gas in clusters and how they change over cosmic time will reveal the history of heating by AGN, galactic winds, and mergers (Voit & Donahue (2005, astro-ph/0509176)

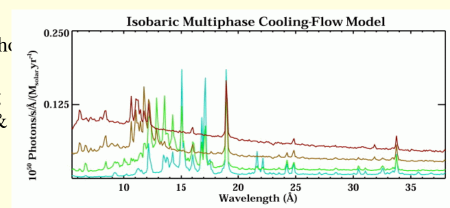

Fig. 5: Spectra of cooling gas, rich in Fe L and other lines, will reveal the chemical composition, gas motions, and level of cooling. Simulated spectra are for gas at temperatures ranging between 6 keV (red) and 0.35 keV (blue). The lines strengthen as the gas cools [Peterson et al. 03, ApJ, 590, 207]